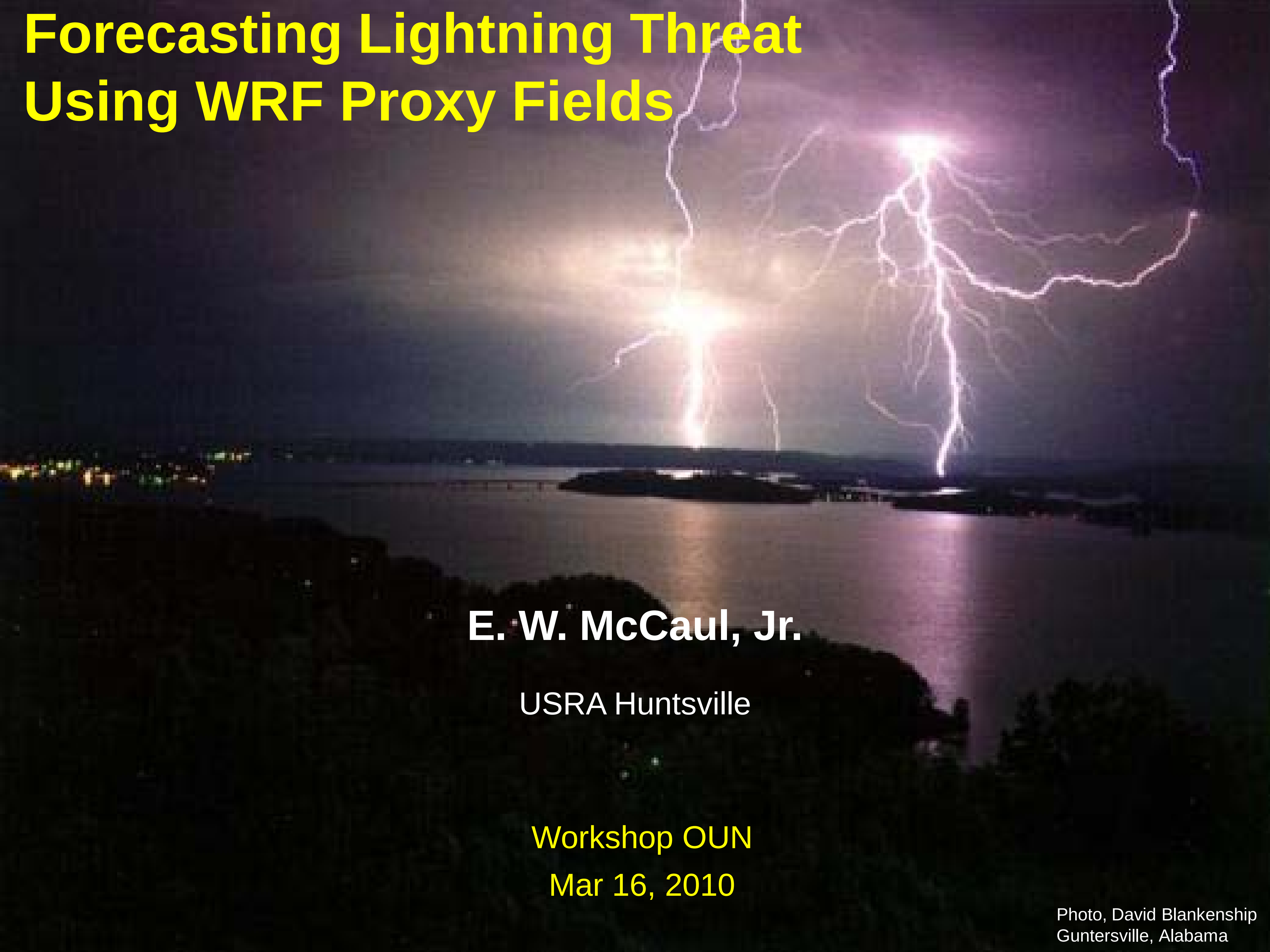
Forecasting Lightning Threat Using WRF Proxy Fields



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Photo, David Blankenship
Guntersville, Alabama

Objectives

Given that high-resolution WRF forecasts can capture the character of convective outbreaks, we seek to:

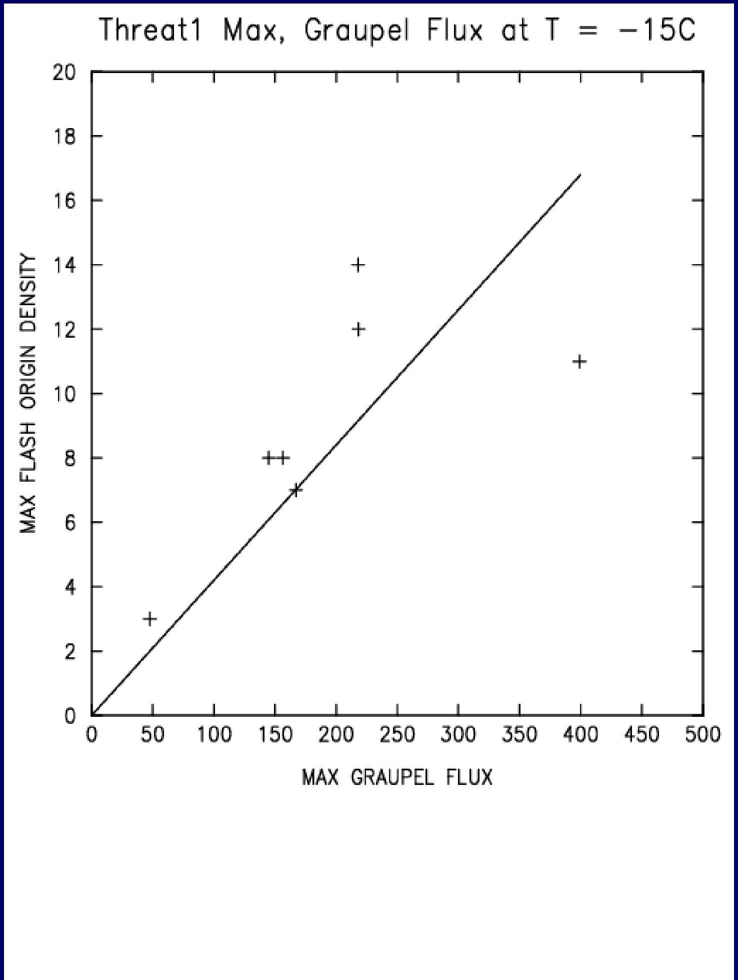
1. Create WRF forecasts of LTG threat (1-24 h), based on 2 proxy fields from explicitly simulated convection:
   - graupel flux near -15 C (captures LTG time variability)
   - vertically integrated ice (captures LTG threat area)
2. Calibrate each threat to yield accurate quantitative peak flash rate densities
3. Also evaluate threats for areal coverage, time variability
4. Blend threats to optimize results
5. Examine sensitivity to model mesh, microphysics

WRF Lightning Threat Forecasts: Methodology

1. Use high-resolution 2-km WRF simulations to prognose convection for a diverse series of selected case studies
2. Evaluate graupel fluxes; vertically integrated ice (VII)
3. Calibrate WRF LTG proxies using peak total LTG flash rate densities from NALMA; relationships look linear, with regression line passing through origin
4. Truncate low threat values to make threat areal coverage match NALMA flash extent density obs
5. Blend proxies to achieve optimal performance
6. Study CAPS 4-km ensembles to evaluate sensitivities

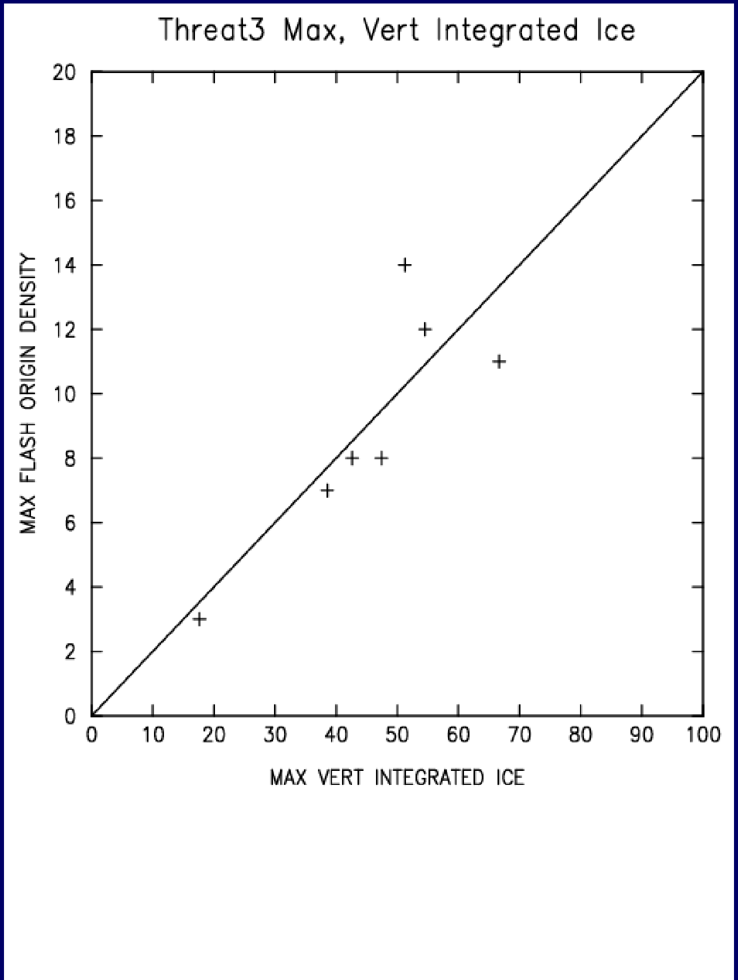
Calibration Curve
Threat 1 (Graupel flux)

$F_1 = 0.042$ FLX



Calibration Curve
Threat 2 (VII)

$F_2 = 0.2$ VII



LTG Threat Methodology: Advantages

- Methods based on LTG physics; should be robust and regime-independent
- Can provide quantitative estimates of flash rate fields; use of thresholds allows for accurate threat areal coverage
- Methods are fast and simple; based on fundamental model output fields; no need for complex electrification modules

LTG Threat Methodology: Disadvantages

- Methods are only as good as the numerical model output; models usually do not make storms in the right place at the right time; saves at 15 min sometimes slightly miss LTG jump peaks
- Small number of cases means uncertainty in calibrations
- Calibrations should be redone whenever model is changed (pending studies of sensitivity to mesh, model microphysics, to be studied here)

WRF Configuration (typical)

30 March 2002 Case Study

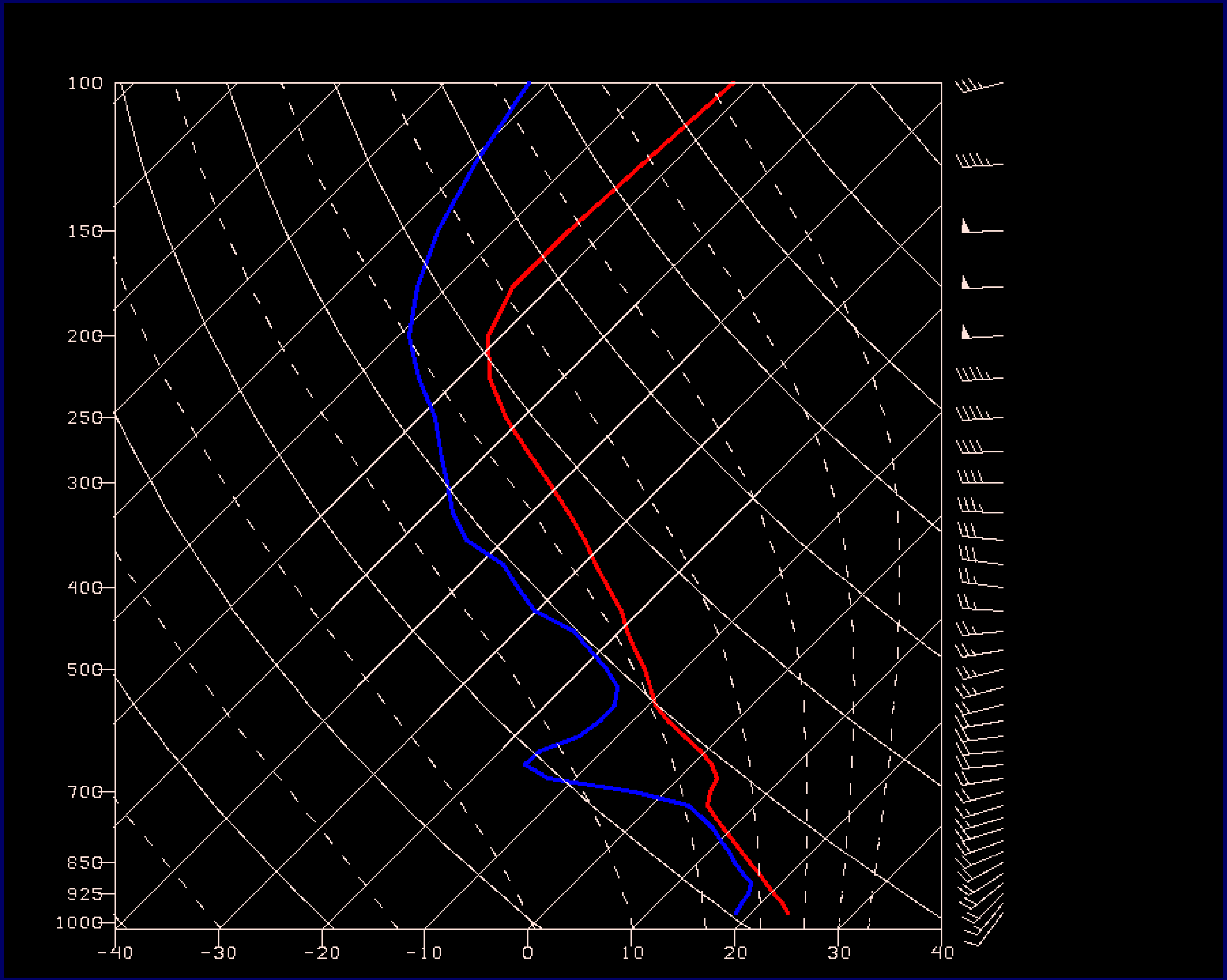
- 2-km horizontal grid mesh
- 51 vertical sigma levels
- Dynamics and physics:
  - Eulerian mass core
  - Dudhia SW radiation
  - RRTM LW radiation
  - YSU PBL scheme
  - Noah LSM
  - WSM 6-class microphysics scheme (graupel; no hail)
- 8h forecast initialized at 00 UTC 30 March 2002 with AWIP212 NCEP EDAS analysis;
- Also used METAR, ACARS, and WSR-88D radial vel at 00 UTC;
- Eta 3-h forecasts used for LBC's

WRF Lightning Threat Forecasts:

Case: 30 March 2002

Squall Line plus Isolated Supercell

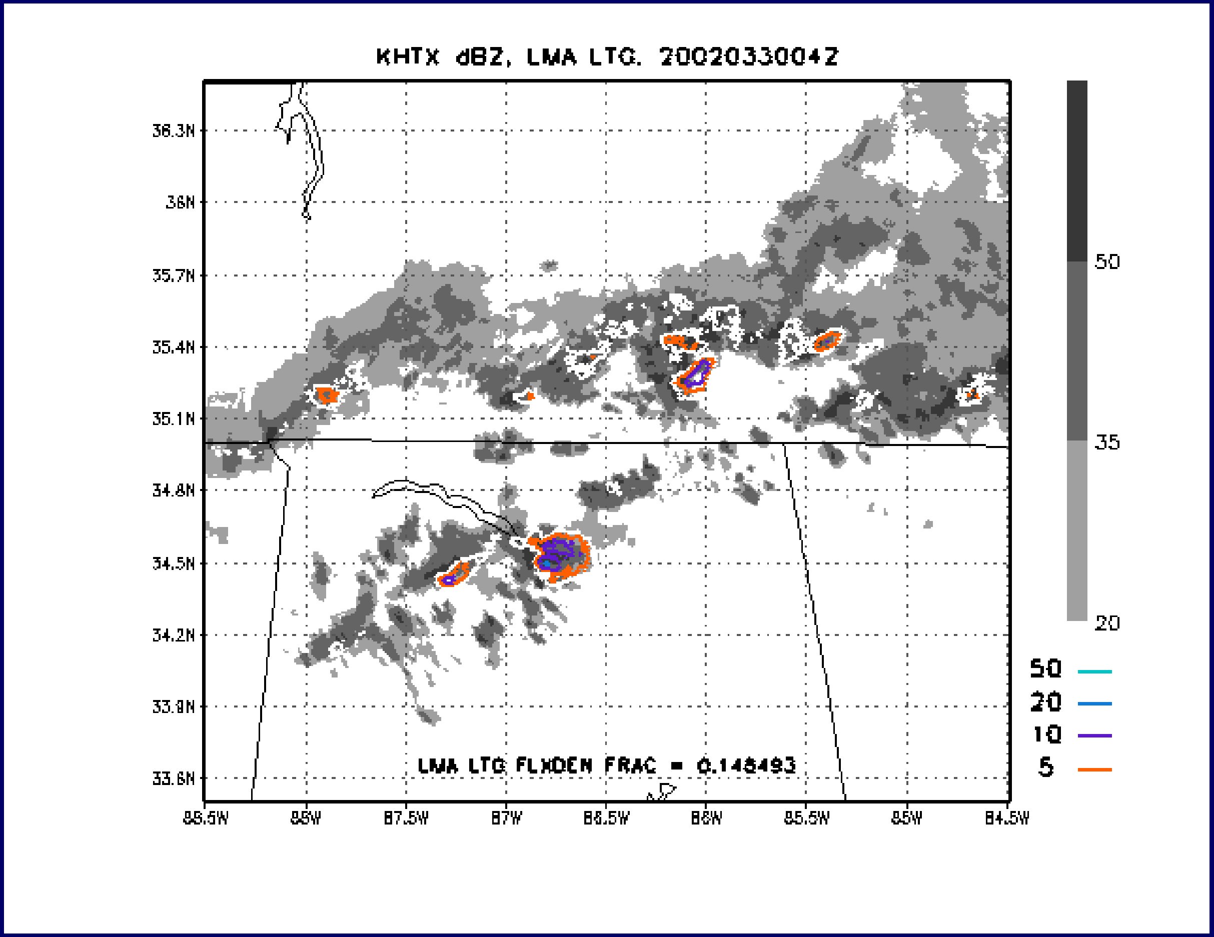
WRF Sounding, 2002033003Z



Lat=34.4
Lon=-88.1
CAPE~2800

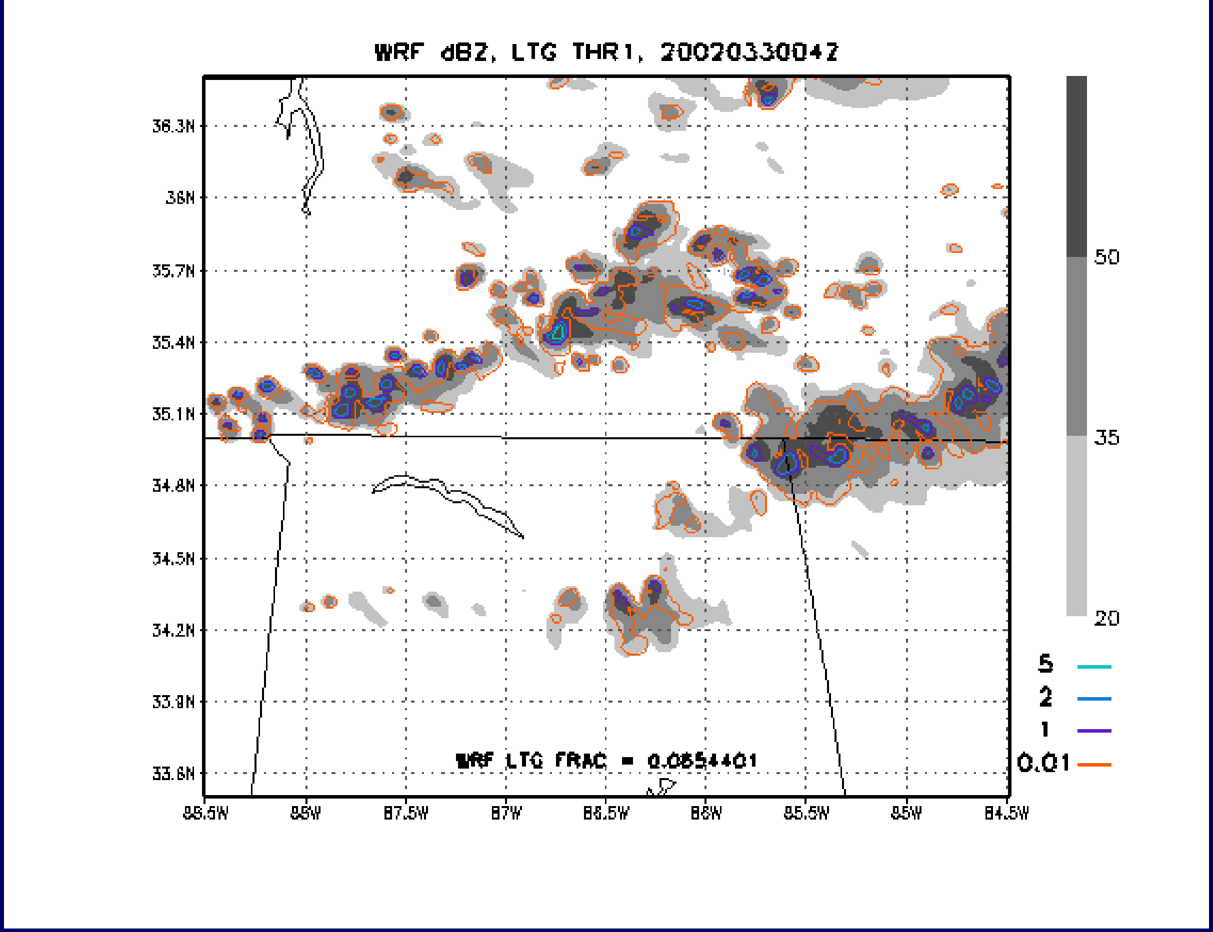
Ground truth: LTG flash extent density + dBZ

30 March 2002, 04Z



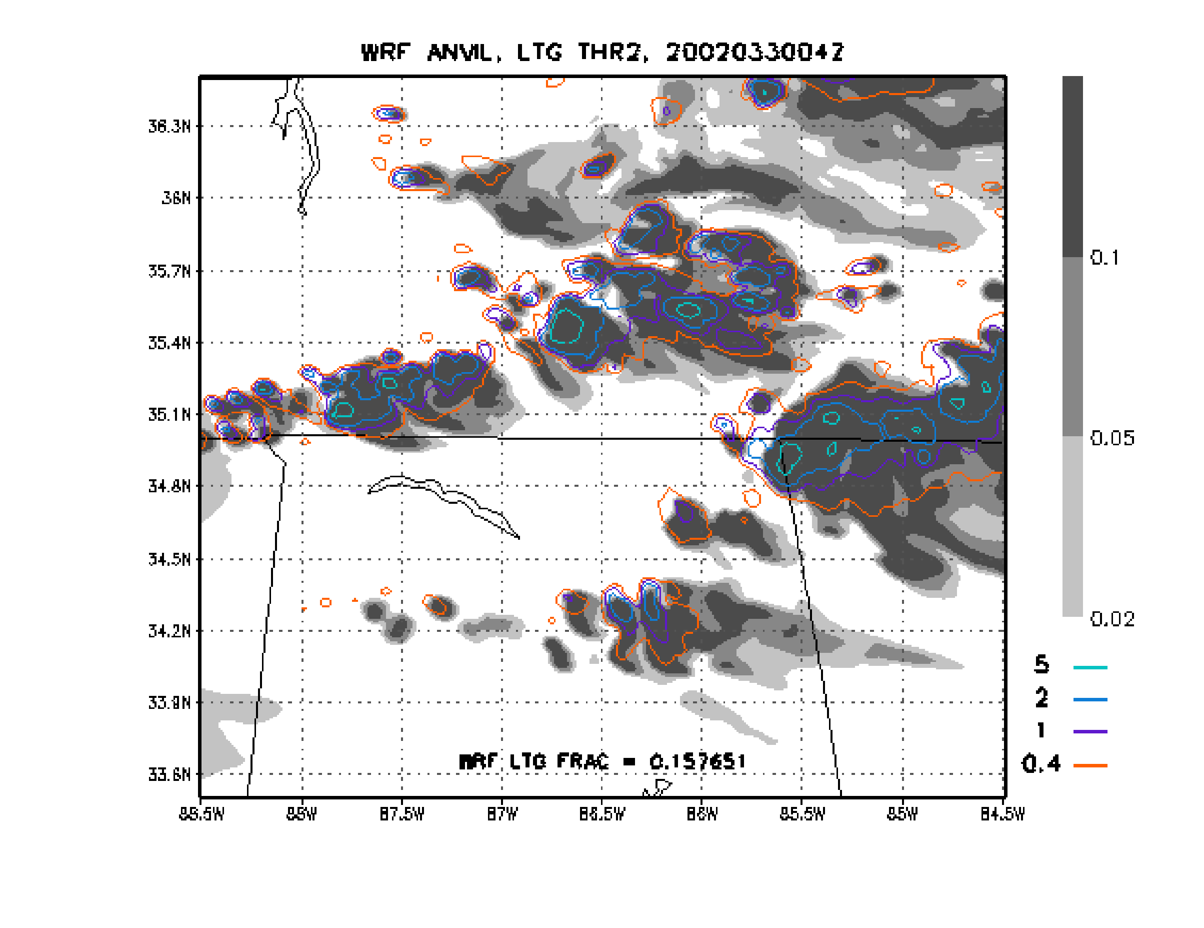
WRF forecast: LTG Threat 1 + dBZ

30 March 2002, 04Z

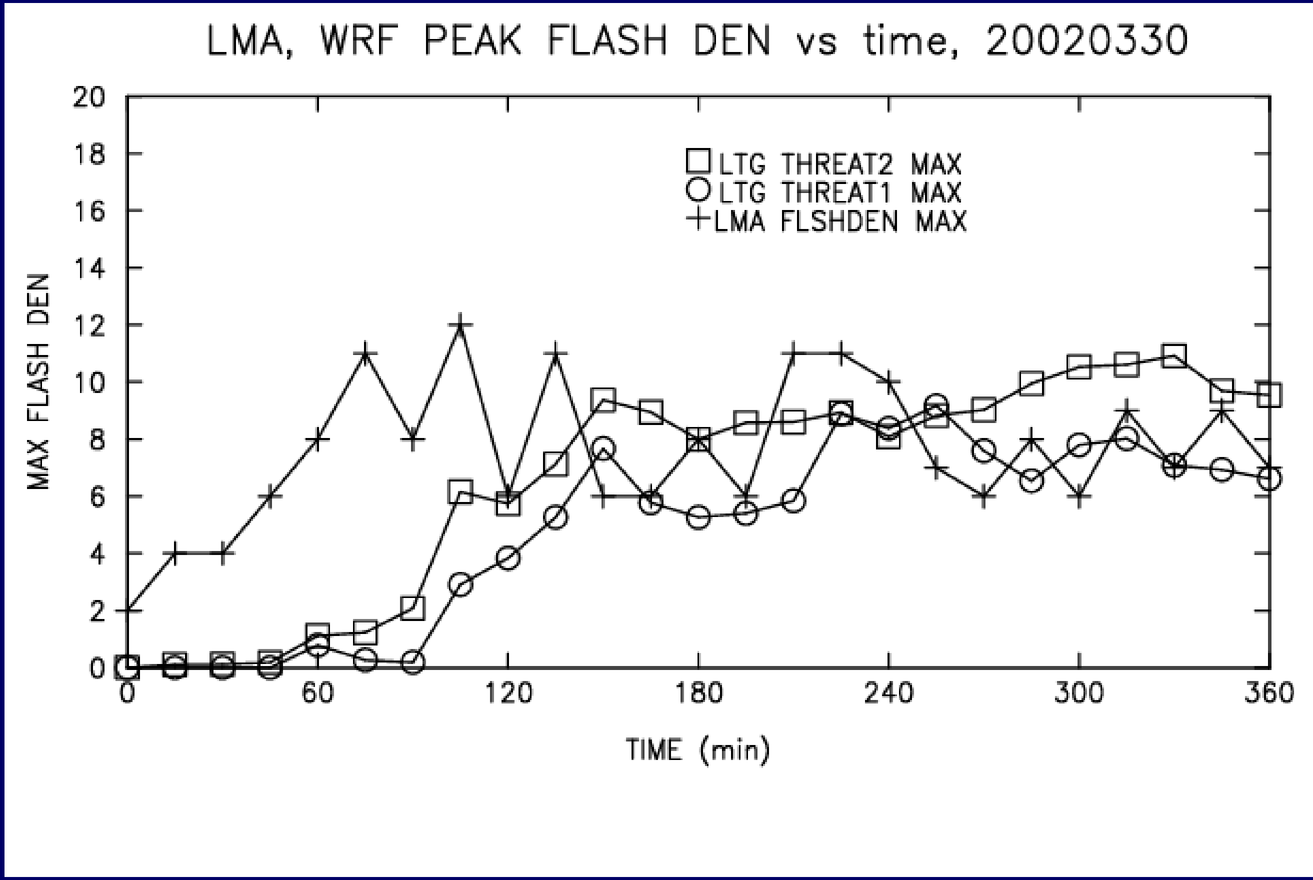


WRF forecast: LTG Threat 2 + anvil ice

30 March 2002, 04Z



Domainwide Peak Flash Density Time Series 30 March 2002



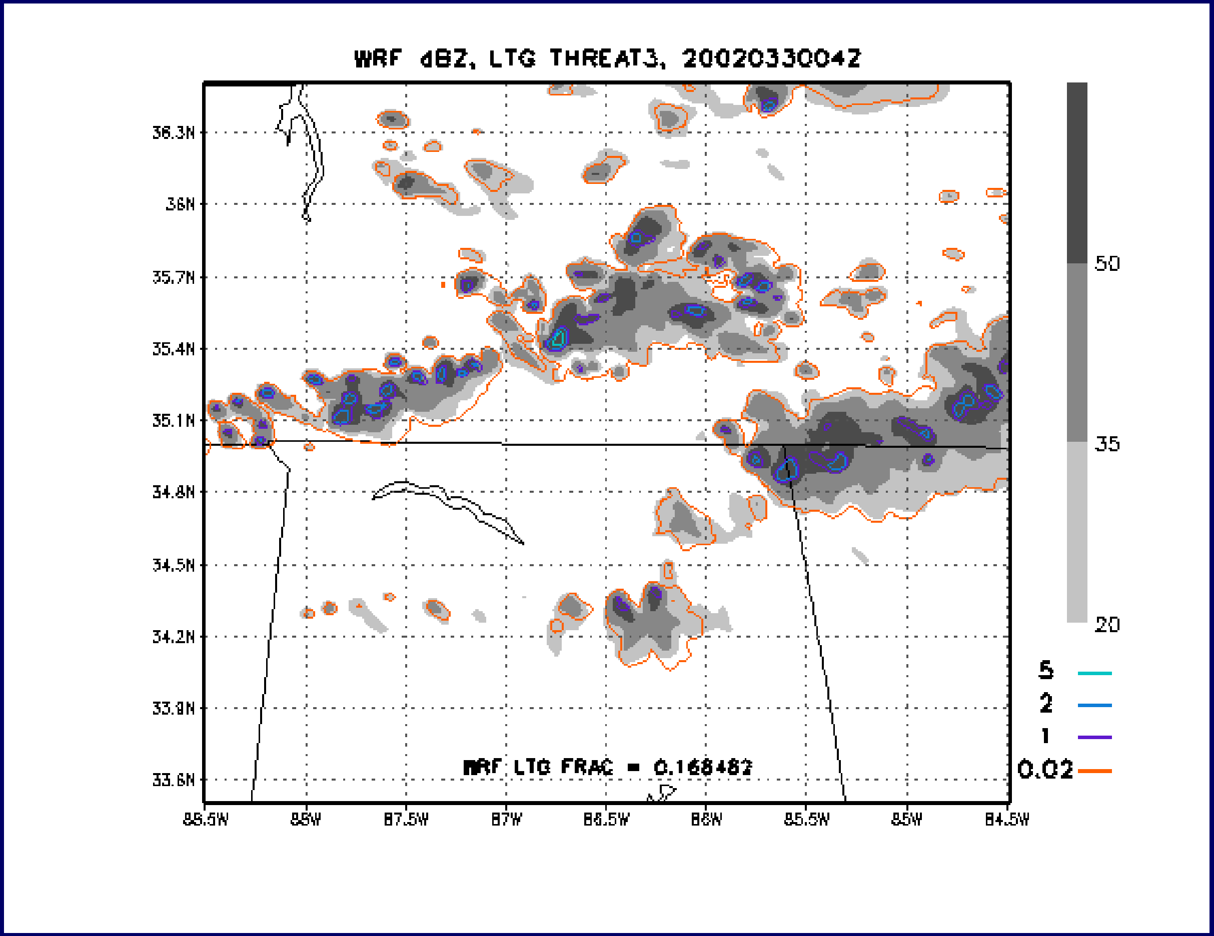
Implications of results:

1. WRF LTG threat 1 coverage too small (updrafts emphasized)
2. WRF LTG threat 1 peak values have adequate t variability
3. WRF LTG threat 2 peak values have insufficient t variability (because of smoothing effect of z integration)
4. WRF LTG threat 2 coverage is good (anvil ice included)
5. WRF LTG threat mean biases can exist because our method of calibrating was designed to capture *peak* flash rates correctly, not *mean* flash rates
6. Blend of WRF LTG threats 1 and 2 should offer good time variability, good areal coverage

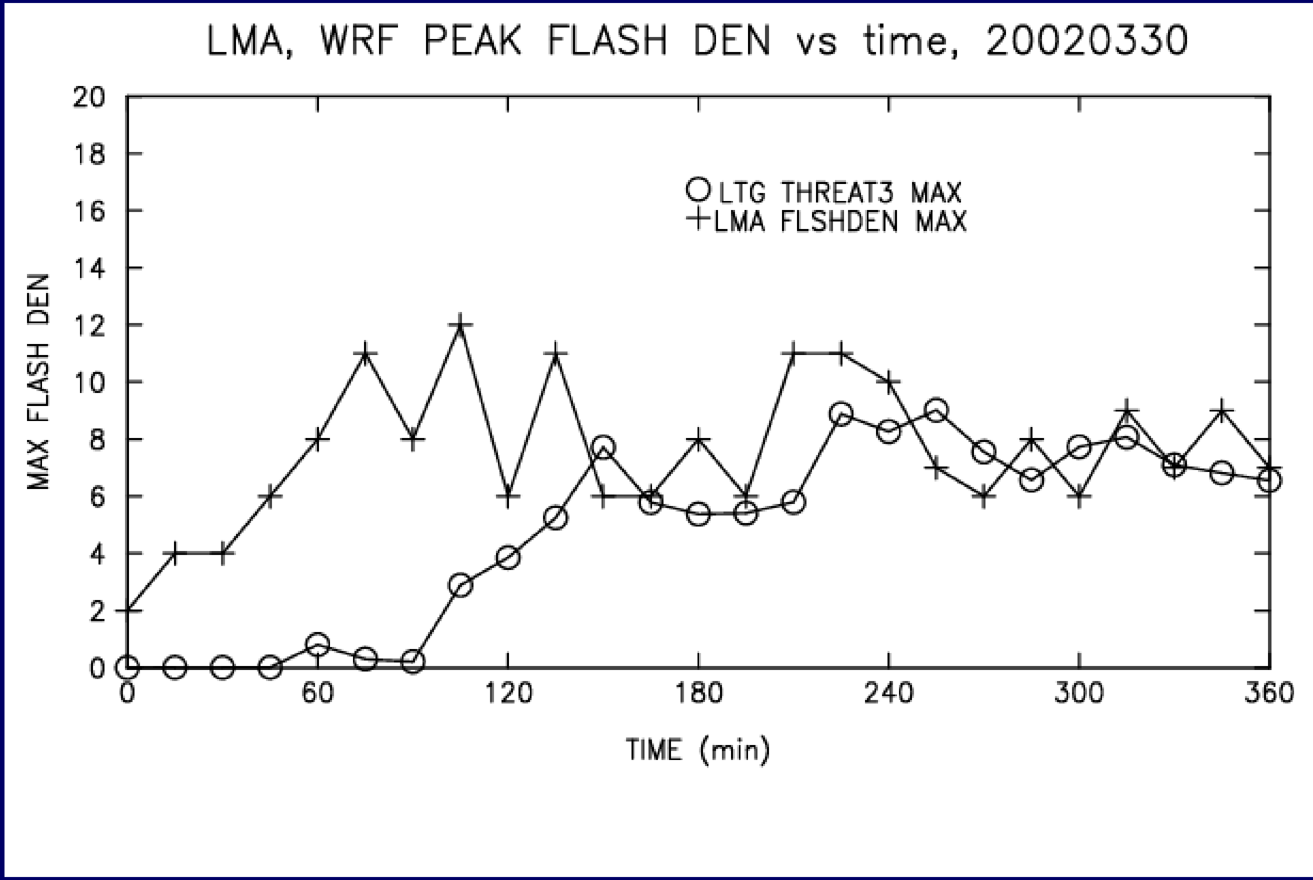
Construction of blended threat:

1. Threat 1 and 2 are both calibrated to yield correct peak flash densities
2. The peaks of threats 1 and 2 tend to be coincident in all simulated storms, but threat 2 covers more area
3. Thus, weighted linear combinations of the 2 threats will also yield the correct peak flash densities
4. To preserve most of time variability in threat 1, use large weight
5. To ensure areal coverage from threat 2, avoid very small weight
6. Tests using 0.95 for threat 1 weight, 0.05 for threat 2, yield satisfactory results

Blended Threat 3; dBZ: 2002033004Z



Domainwide Peak Flash Density Time Series



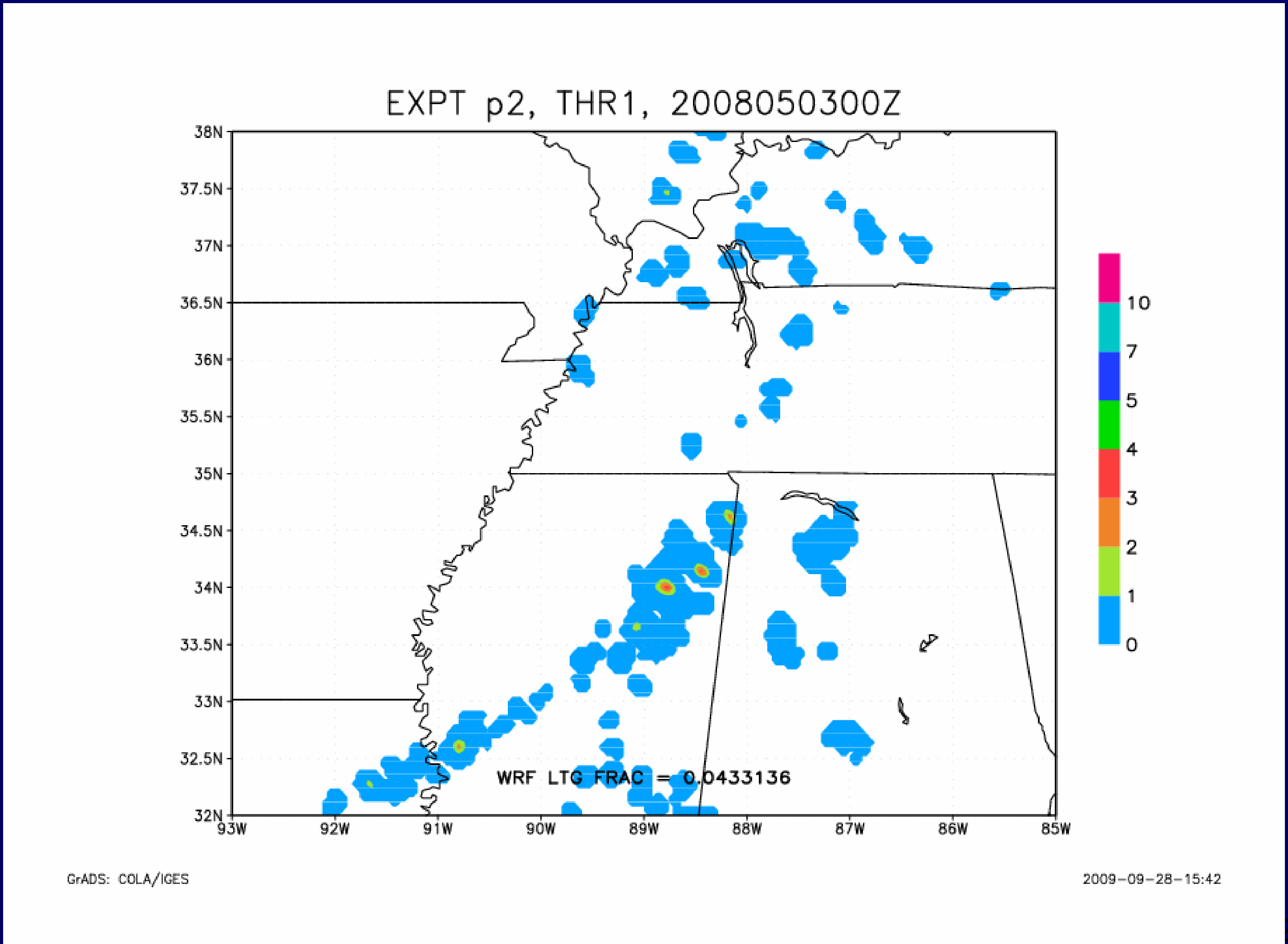
Ensemble studies, CAPS case 20080502:

1. Tornadic storms in MS after 20Z on 20080502
2. NALMA saw only peak FRD ~ 7 fl/km^2/(5 min) due to range
3. Results obtained for 10 ensemble members (see table, next):
   - several members didn't finish (computer issues)
   - consider only data from t > 16 hr
   - model output available only hourly
   - to check calibrations, must use mean of 1-h NALMA peaks
   - Threat 1 always smaller than Threat 2
   - Threat 2 values look reasonable for severe outbreak
   - Threat 1 shows more sensitivity to grid change than Threat 2
4. Results suggest a strategy for generalizing WRF LTG threat algorithm:
   - use Threat 2 peaks to rescale Threat 1 peaks
   - after recalibrating Threat 1, continue with threat blending

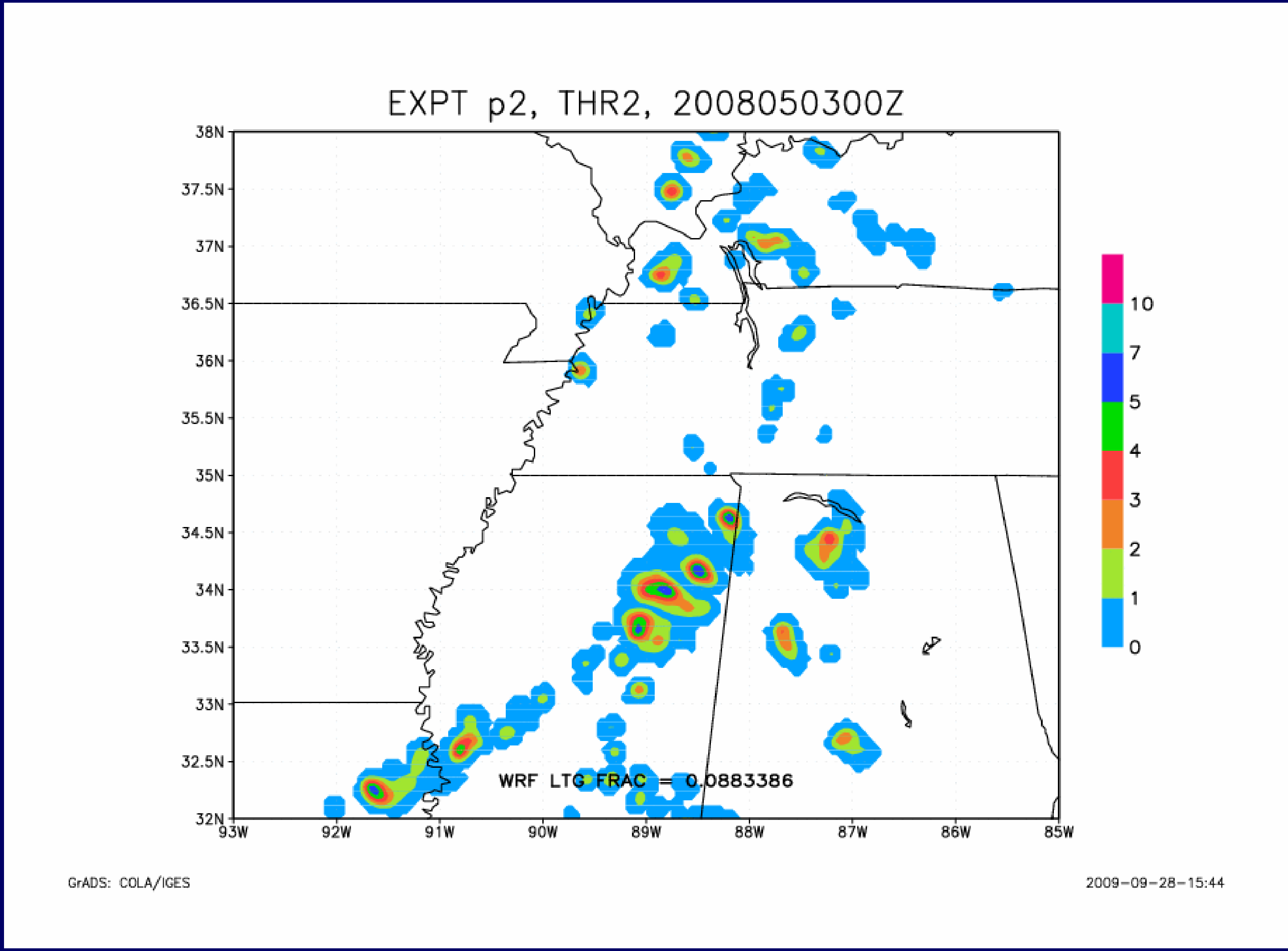
Results, CAPS ensemble, 20080502

Experiment name	Peak Threat 1	Peak Threat 2
cn	4.1 at t=17 hr	6.7 at t=24 hr
c0	4.0 at t=23 hr	8.0 at t=23 hr
n1	6.6 at t=21 hr	9.4 at t=22 hr
n2	5.0 at t=24 hr	7.6 at t=24 hr
n3 (short expt)	2.5 at t=16 hr	6.7 at t=16 hr
n4	7.1 at t=29 hr	9.2 at t=25 hr
p1	7.2 at t=21 hr	8.4 at t=21 hr
p2	5.5 at t=22 hr	8.1 at t=20 hr
p3	6.4 at t=23 hr	8.9 at t=23 hr
p4	3.6 at t=23 hr	7.6 at t=21 hr

CAPS p2, Threat 1: 2008050300Z



CAPS p2, Threat 2: 2008050300Z



Ensemble studies, CAPS case 20080510:

1. Tornadic storms in MS,AL after 00Z on 20080511
2. NALMA saw mean peak FRD ~ 10.5 fl/km^2/(5 min); system more intense than any used in original algorithm study
3. Results obtained for 10 ensemble members (see table, next):
   - weekend timing forced use of runs starting 00Z 20080510
   - model output available only hourly
   - to check calibrations, use mean of 1-h NALMA peaks
   - Threat 1 usually smaller than Threat 2
   - Threat 2 values look reasonable for severe outbreak
   - Threat 1 shows more sensitivity to grid change than Threat 2
4. Results show WRF storm intensity consistent with obs, support proposed strategy for generalizing WRF LTG threat algorithm

Results, CAPS ensemble, 20080510

Experiment name	Peak Threat 1	Peak Threat 2
cn	12.8 at t=23 hr	12.9 at t=23 hr
c0	10.7 at t=21 hr	13.0 at t=21 hr
n1	8.3 at t=23 hr	10.5 at t=21 hr
n2	11.5 at t=21 hr	11.7 at t=21 hr
n3	6.6 at t=23 hr	9.2 at t=24 hr
n4	11.8 at t=22 hr	10.4 at t=22 hr
p1	9.8 at t=24 hr	10.1 at t=26 hr
p2	10.5 at t=24 hr	8.9 at t=25 hr
p3	9.5 at t=23 hr	9.6 at t=25 hr
p4	8.4 at t=23 hr	10.7 at t=23 hr

General Conclusions:

1. LTG threats 1 and 2 yield reasonable peak flash rate densities, but with some sensitivity to mesh, physics changes (see next p.)
2. LTG threats provide more realistic spatial coverage of LTG than that suggested by coverage of CAPE>0, which overpredicts threat, especially in summer
3. Blended threat retains proper peak flash rate densities, because constituents are calibrated and coincident
4. Blended threat retains temporal variability of LTG threat 1, but offers proper areal coverage, thanks to threat 2

Ensemble findings (preliminary):

1. Currently testing technique on CAPS 2008 4km WRF runs
2. Two cases yield consistent, similar results
3. Results sensitive to changes in grid mesh, model physics
   - Threat 1 too small, more sensitive (grid mesh sensitivity?)
   - Threat 2 appears nearly independent of model changes
   - Strategy: boost Threat 1 to equal Threat 2 peak values before creating blended Threat 3
4. Must examine additional case days to establish generality

Future Work:

1. Plan: examine more simulation cases, with added diversity
2. Test newer versions of WRF, when available:
   - more hydrometeor species
   - double-moment microphysics
3. Run on 1-km or finer grids; study PBL scheme response
4. In 2010 runs, examine fields of interval-cumulative wmax, and associated hydrometeor and reflectivity data, not just the instantaneous values; for save intervals >15 min, events happening between saves may be important for LTG jumps
5. The two threats may offer opportunities for devising data assimilation strategies based on observed total LTG

Acknowledgments:

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